International Journal of Medicine and
Pharmaceutical Sciences (IJMPS)
ISSN(P): 2250-0049; ISSN(E): 2321-0095
Vol. 5, Issue 1, Feb 2015, 67-76

YIELDS FOR THE PRODUCTION OF PHOSPHORUS-32 USING THE CHARGED AND UNCHARGED PARTICLES IN MEDICAL PRACTICE

BASHAIR MOHAMMED SAIED[1], NAWAL FATTAH NAJI[2] & A.L. MOHAMED ABD AL-AMEER[3]

[1]College of Education, Ibn-Al-Haitham, University of Baghdad, Iraq

[2,3]Al-Kindy College of Medicine, University of Baghdad, Iraq

ABSTRACT

Phosphorus-32 is one of the radioisotopes which has found more applications as tracer in such diverse fields as biology, medicine, gauging and agriculture. Phosphorus-32 is a radionuclide suitable for labeling a wide range of radiopharmaceuticals emitting beta particles (1.71 MeV) as well as for local therapy of tumors. Among the possible methods for cyclotron production of Phosphorus-32 we investigate the proton irradiation on, natural (Nickel, Iron, Silver and Vanadium). The proton and deuteron irradiation on different isotopes Sulfur, Cobalt, Silicon, Gold, Thorium targets we are considered .The reactor production method on Sulfur are considered in this paper. The total integral yield based on the main published and approved experimental results of excitation functions were calculated.

KEYWORDS: ^{32}P Production, Excitation Function, Integral Yield, Isotopes of Sulfur, Nuclear Medicine

INTRODUCTION

The phosphorus-32 radioisotope (T1/2 = 14.28 days) has a large applications in medicine, biochemistry and molecular biology where it can be used to trace phosphorylated molecules, e.g. in elucidating metabolic pathways, and radioactively label DNA' therapeutic uses include treatment of polycythemia vera, chronic myelocytic leukemia, chronic lymphocytic leukemia, and palliation of metastatic skeletal disease, and treatment of intraperitoneal and intrapleural malignant effusions resulting from metatstatic disease. It may also be given by injection to treat cancer in certain organs such as the ovaries and prostate. so decays rapidly by beta decay as shown in this nuclear equation(1)[1]:

$$^{32}P \longrightarrow 32\ Si + \beta^{-} + \nu^{-} \qquad (1)$$

The phosphorus-32 can be produced in nuclear reactors by exposing suitable target materials to a neutron flux (usually 10^{13}-10^{14} n/cm^2.s) for an appropriate period of time. Accelerators are used to produce isotopes by bombarded appropriate targets with beams of charged nuclei impinge on targets to produce the required isotope. The electron capture is mostly founded on proton and deuteron irradiation of S, Si, and Co targets by a cyclotron. In this work theoretical excitation functions of ^{32}P productions were calculated using different charged energetic particles. Theoretical calculations of the production yields were done using SRIM (Stopping Range of Ions in Matter) code [2] to determine the suggested possible optimum reaction in ^{32} P production.

METHODS

Nuclear data play a very important role in the choice of a radioisotope for a medical application. Nuclear structure and the decay data determine the suitability of a radioisotope for diagnostic application while the nuclear reaction data

study the possibility of its production in a pure form**.**

The feasibility of the production of ^{32}P via various nuclear reactions was investigated. Excitation functions of ^{32}P production by the reactions of ^{34}S+d, ^{197}Au+p, ^{30}Si+ d, ^{30}Si+ n, ^{nat}Fe+ p, ^{nat}Ni+ p, ^{nat}Co+ p, ^{nat}Ag+ p, and ^{232}Th+ p were calculated using the available data in the international libraries. According to SRIM code, the thick target integral yields were deduced using the calculated evaluated cross sections. A Matlab sub programs was used to solve the following yield equation (2)[3]:

$$Y = NP\sigma(E).10^{-30}(1 - e^{-\lambda t}) \qquad (2)$$

Whereas, $\sigma(E)$ (mb) is the average cross section at a specific energy (E); N is the number of target atoms/cm2, λ is the decay constant of the produced isotopes, P is the number of incident protons/sec for (1 μA) and t is the irradiation time (t= 1 h). The integral target yield is calculated by summing up the differential yields.

The production yield of isotopes using reactors can be calculated taking in to consideration the radiation period and the reactor flux using equation (3)[4]

$$A = N\sigma(E)\varphi(1 - e^{-\lambda tirr})*(e^{-\lambda td}) \qquad (3)$$

Whereas N: is the total number of atoms, $\sigma(E)$: is the neutron activation cross-section leading to the production of radioisotope of interest in (mb),φ: is the flux in n/cm^2/s, td: is the time of Cool, tirr: is the time of irradiation, λ:is the decay constant .

RESULTS AND DISCUSSIONS

Calculation of Excitation Function

- **Cyclotron Production of**^{32} P

A- ^{nat} Fe(p,x)^{32} P reaction

The excitation functions of the proton induced reaction on ^{nat} Fe were determined by equation(2) and SRIM code (Figure 1, Figure 2). The evaluation of the results of the calculations showed that the best range of energy that favors the reaction is from (130 to 396) MeV. According to G. V. S. Rayudu [5] This reaction appears to be good for the purpose of ^{32}P production. The same reaction ^{nat} Fe (p, x)^{32} P, but the range of energy(500 to 2900)Mev According to G. V. S. Rayudu [5] (Figure 3, Figure 4) appears is not useful for the purpose of ^{32}P Production.

B- **^{nat}Ni(p, x)** ^{32} P reaction

Experimental data reported by G. V. S. Rayudu [5]], for the energies (130 and 400 mev), whereas higher energy range is required to find the modest excitation function of the **^{nat}Ni(p, x)** ^{32} P reaction(Figure 1, Figure 2). The same reaction **^{nat}Ni(p, x)** ^{32} P reaction, but the range of energy(500 to 2900) Mev According to G. V. S. Rayudu [6] (Figure 3, Figure 4) appears not to be suitable for the purpose of ^{32}P Production (Figure 3, Figure 4) .

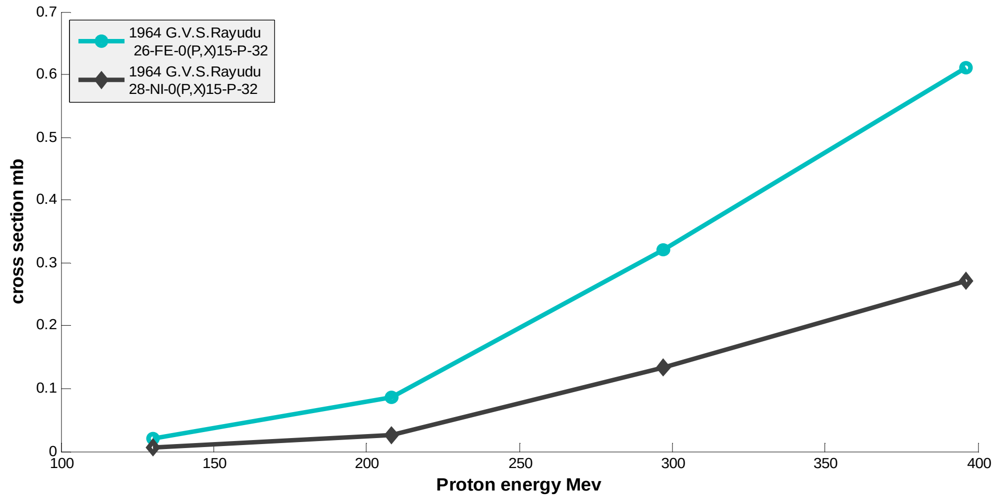

Figure 1: Cross Sections of ^{32} P **of the Two Reactions** ^{nat} Fe(p, x), ^{nat}**Ni(p, x)**

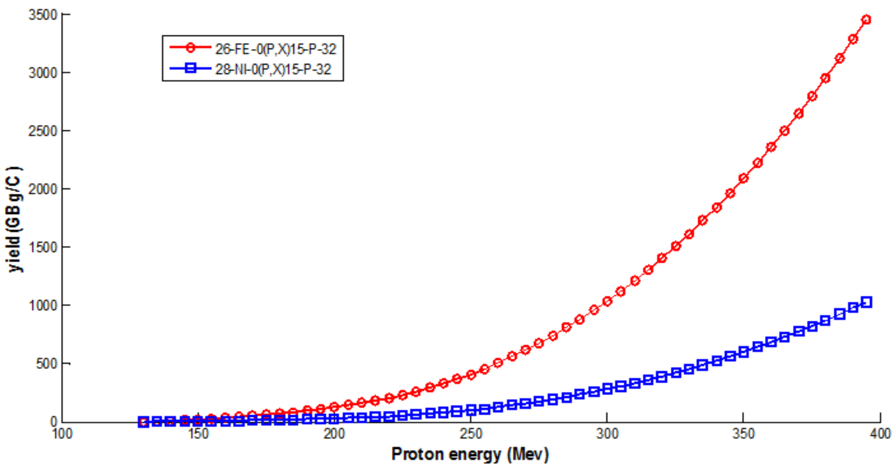

Figure 2: The Excitation Functions of ^{32} **P of the Two Reactions** ^{nat} **Fe(p, x),** ^{nat}**Ni(p, x)**

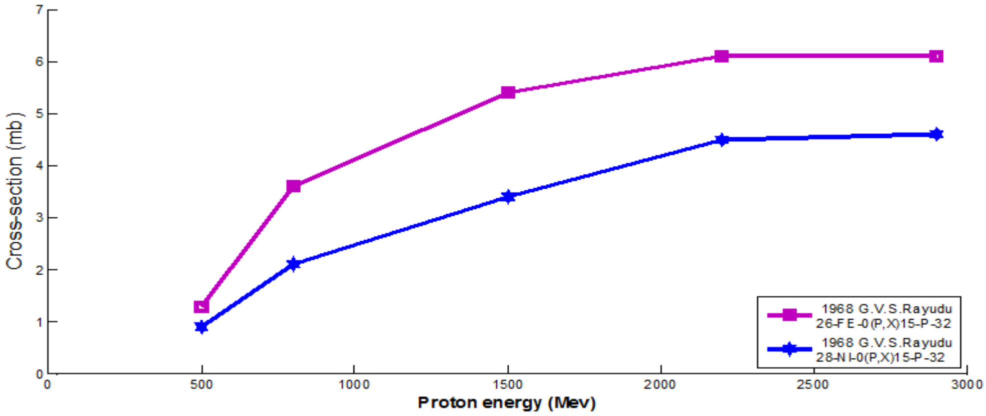

Figure 3: Cross Sections of ^{32} P **of the Two Reactions** ^{nat} Fe(p, x), ^{nat}**Ni(p, x)**

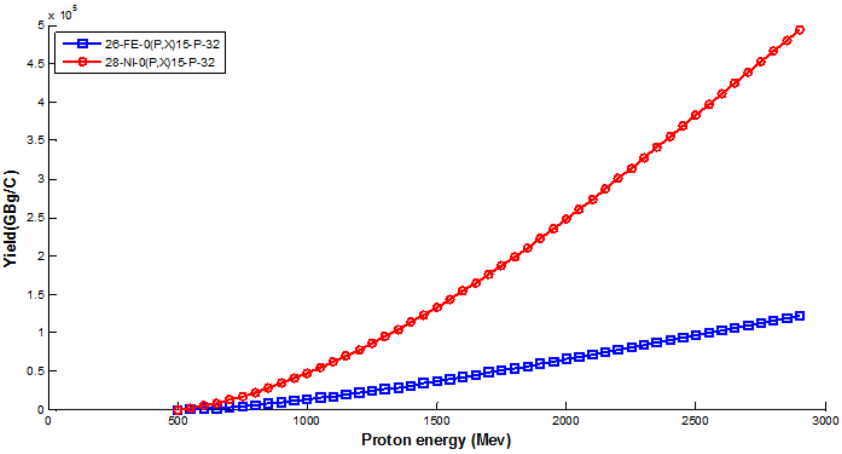

Figure 4: The Excitation Functions of ^{32} P of the Two Reactions ^{nat} Fe(p, x), ^{nat}Ni(p, x)

C – nat Ag(p, x) 32 P, 59Co(p, x) 32 P, 197Au(p, x) 32 P reactions

The Excitation functions of ^{nat}Ag (p, x), ^{59}Co (p, x) and ^{197}Au (p, x) reactions according to G. N. Simonoff, C. Vidal[7] ,appears the ^{59}Co(p, x) is the best method to produce ^{32} P in high energies (Figure 5, Figure 6).

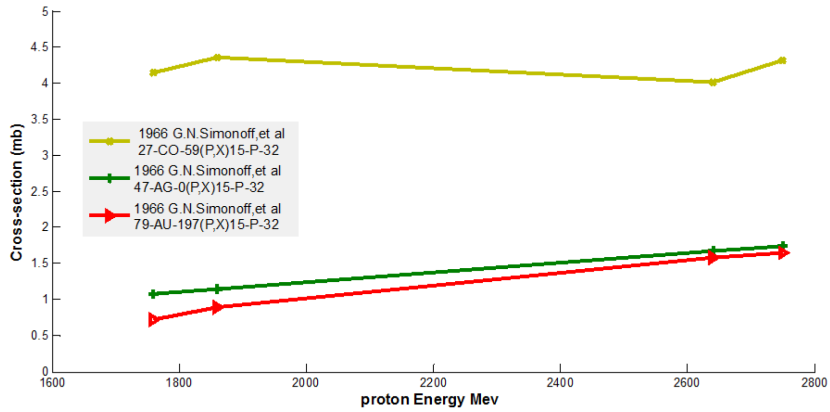

Figure 5: Cross Sections of ^{32} P of the Three Reactions ^{nat}Ag(p, x), ^{59}Co(p, x) ,^{197}Au(p, x)

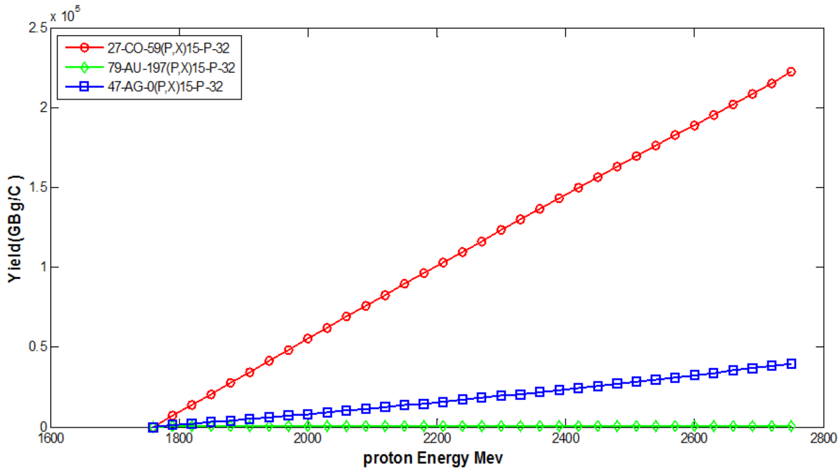

Figure 6: The Excitation Functions of ^{32} P of the Three Reactions ^{nat}Ag(p, x), ^{59}Co(p, x) ,^{197}Au(p, x)

D- ^{34}S(d,a) ^{32} P reaction

The reaction $^{34}S(d, a)$ has a useful range for deuterons to produce the ^{32}P. According to O. U. Anders, W. W. Meinke [8] the range of energy for the production of this reaction was found to be from (0 to 18) MeV. The maximum cross section obtained is 330 mb in 7.7 MeV(Figure7). The calculated thick-target yield using (eq.2) is 70 GBq/C(Figure8). This reaction appears to be very good for the purpose of ^{32}P production.

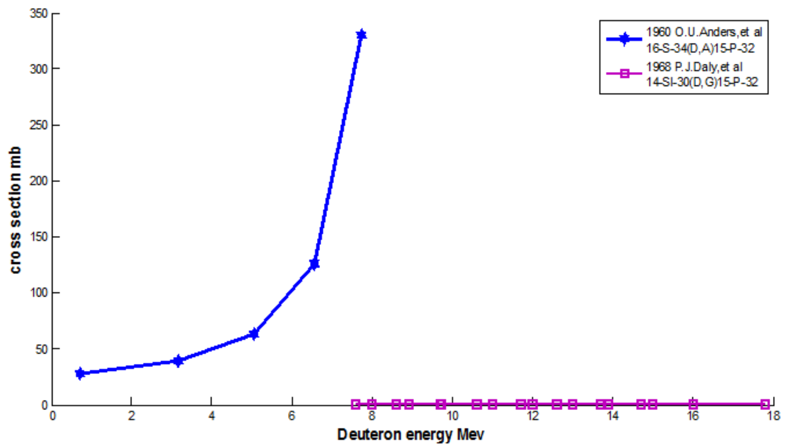

Figure 7: Cross Sections of 32 P of the Two Reactions 34S(d, a), 30Si(d, γ)

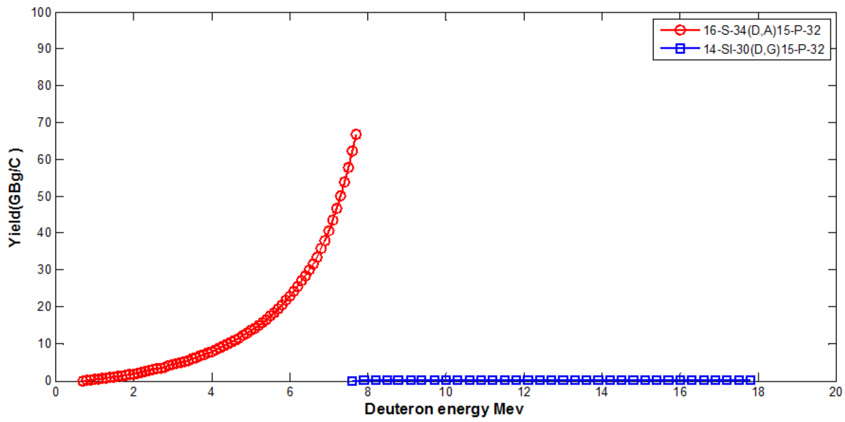

Figure 8: The Excitation Functions of ^{32} P of the Two Reactions ^{34}S(d, a), ^{30}Si(d, γ)

E- $^{30}Si(d,\gamma)$ ^{32} P reaction

The reaction $^{30}Si(d, \gamma)$,as mentioned in the work of P. J. Daly et al [9] shows that the best range of deuterons offered an energy range for the production of ^{32}P was found to be in the(0 to18) MeV. **Yields Calculations for Induced by Deuterons (**Figure 7, Figure 8). It's clear that this reaction is not useful for the purpose of production.

F - 232Th (P,x)32P reaction

The Excitation functions 232Th (P,x)32P reaction according to G.N.Simonoff, C.Vidal[7] ,appears the 232Th (P,x) is the very good method to produce 32 P ,but in high energies (Figure 9,Figure 10).

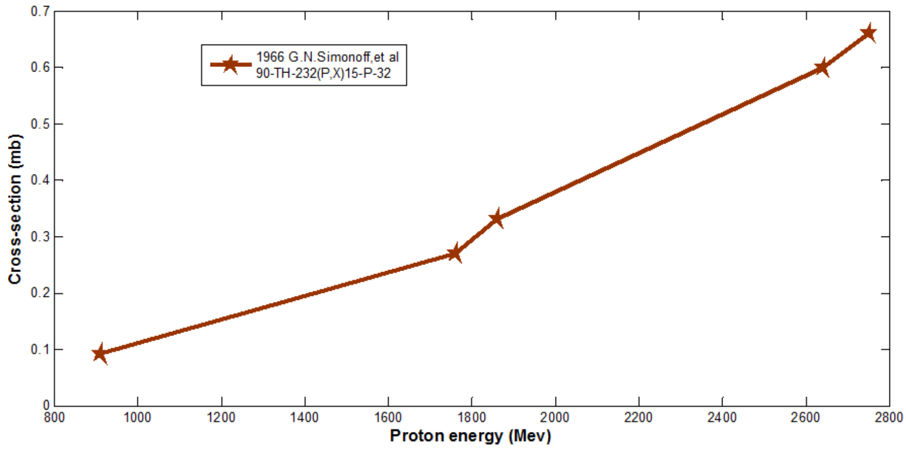

Figure 9: Cross Sections of ^{32}P of the ^{232}Th (P, x)^{32}P Reaction

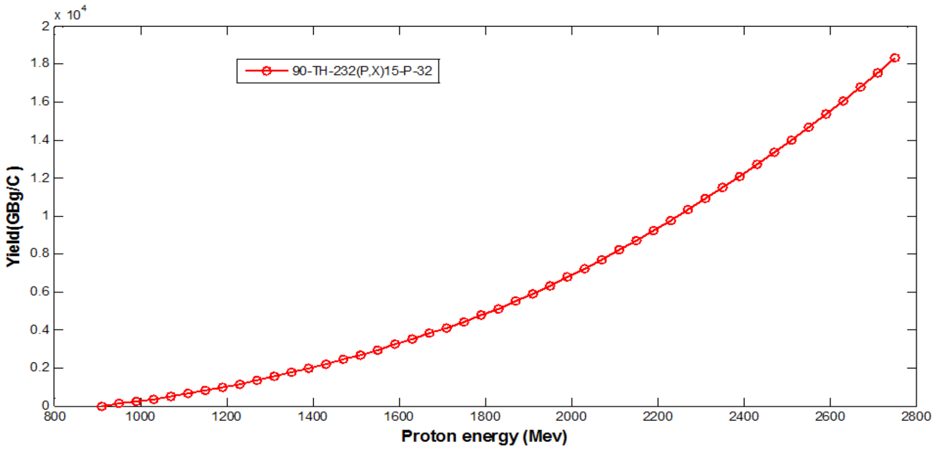

Figure 10: The Excitation Functions of ^{32}P of the ^{232}Th (P, x)^{32}P Reaction

- **Production of ^{32}P by Neutron**

^{32}S (n, p) ^{32}P reaction

Two possibilities to produce ^{32}P, either by ^{31}P(n, γ) ^{32}P (thermal neutrons) or ^{32}S(n, p)^{32}P (fast neutrons). We chosen the second one because of to purify the S target by distillation is relatively easy [10] ,while the impurities of P and phosphates are difficult to manage and reduce and the Abundance of ^{32}S is (95.02%)[11] .

The excitation functions of the neutron induced reaction on ^{32}S were determined by equation(3) with neutron flux : 1×10^{12} n/cm^2/s, in table 1 and the cross section in (Figure 11) according E. D. Klema, A.O. Hanson[12], R. Ricamo et al[13] , L. Allen Jr et al[14], D.C. Santry, J. P. Butler[15], A. Paulsen, H. Liskien[16] and A. A. Lapenas et al[17].

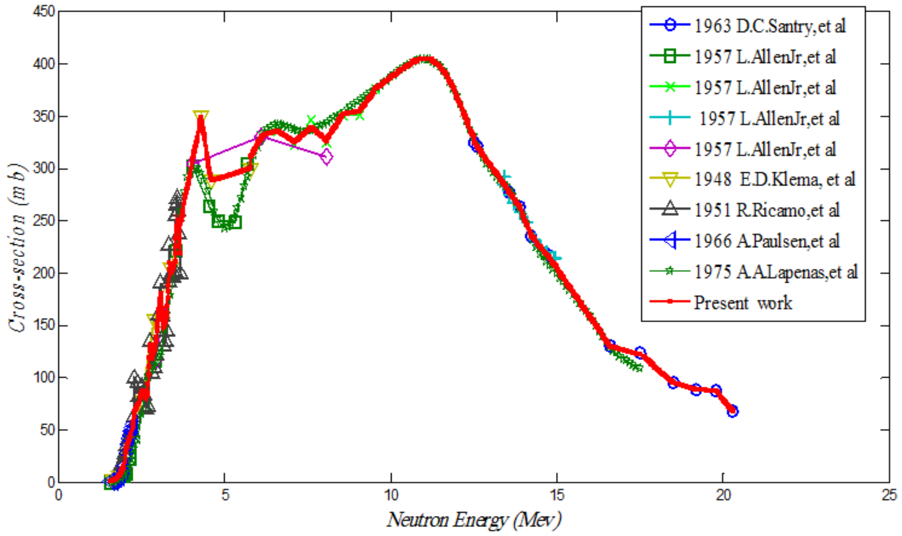

Figure 11: Cross Sections of ^{32} P of the ^{32} S (n, p)^{32}P Reaction

CONCLUSIONS

The production of ^{32} P can be obtained using different nuclear reactions ,for low proton energies (0 to 18)MeV the reaction ^{34}S(d, a) gives best yield (70 GBq/C)(Figure 8) ,while for the other possible reactions as the ^{nat}Fe and ^{nat} Ni which occurs in an energy range greater than (130 to 2900) Me V, the possible yields is in the order of (3550 to 5*10^5)(GB q/ C) (Figure 2, Figure 4).

The reaction^{232}Th (P, x) is good method to produce ^{32} P, but in high energies (Figure 10).

The protron reactions play an important role too in ^{32}P production in^{59}Co (p,x) ,but with high energies the yield of is about (2.3*10^{5}GBq/C) (Figure 6).

A maximum yield can be obtained by the reaction 32S (n, p) 32 P table 1 with 8 weeks Irradiation, to produce 32P by irradiating a target of purified S with neutron flux, has been totally successful [18].

Table 1: Irradiation: A Typical Irradiation of 10 G of Purified Sulphur-32

Irradiation : a Typical Irradiation of 10 g of Purified Sulphur-32 at a Flux of 1 × 10^{12}n/cm^2/s , for 4 Weeks and 8 Weeks with Cooling Period about One Week to Produces					
Neutron Energy	Cross-Section	Four Week		Eight Week	
(Mev)	barns	GBp/g	mCi/g	GBp/g	mCi/g
2	0.0200442	1.896767	51.26396	2.3831	64.40801802
2.5	0.0831954	7.872729	212.7765	9.89129	267.3322391
3	0.1555659	14.72111	397.8679	18.4956	499.8810239
3.5	0.2102817	19.89883	537.8062	25.0009	675.6994233
4	0.3005789	28.4436	768.7458	35.7365	965.8519326
4.5	0.3079313	29.13935	787.55	36.6107	989.477447
5	0.2914047	27.57546	745.2826	34.6458	936.3726869
5.5	0.2968016	28.08616	759.0854	35.2874	953.7145488
6	0.3231416	30.5787	826.4512	38.4191	1038.352946
6.5	0.3349804	31.69899	856.7295	39.8266	1076.394571
7	0.3271884	30.96164	836.801	38.9002	1051.356418
7.5	0.3361902	31.81348	859.8237	39.9704	1080.282146
8	0.3285296	31.08855	840.2312	39.0596	1055.66611
8.5	0.3478922	32.92083	889.7523	41.3617	1117.88435

Table 1: Contd.,

9	0.3538067	33.48052	904.8788	42.0649	1136.88931
9.5	0.3734419	35.33859	955.0969	44.3994	1199.983376
10	0.387	36.62158	989.7724	46.0113	1243.549546
10.5	0.398	37.6625	1017.905	47.3191	1278.895915
11	0.404	38.23028	1033.251	48.0325	1298.175753
11.5	0.397	37.56787	1015.348	47.2003	1275.682609
12	0.369	34.91825	943.7364	43.8713	1185.710032
12.5	0.33	31.2277	843.9919	39.2345	1060.391086
13	0.302807	28.65444	774.4445	36.0014	973.0116609
13.5	0.2808222	26.57403	718.2171	33.3876	902.3675983
14	0.2540497	24.04057	649.7452	30.2046	816.3396283
14.5	0.225003	21.2919	575.4568	26.7511	723.0037162
15	0.2043225	19.33492	522.5653	24.2924	656.5507833
15.5	0.1812264	17.14934	463.4957	21.5464	582.3358279
16	0.1581149	14.96231	404.3869	18.7986	508.0715023
16.5	0.1346226	12.73925	344.3042	16.0056	432.5835803
17	0.1261222	11.93487	322.564	14.995	405.2692541
17.5	0.1216817	11.51467	311.2073	14.467	391.0007138
18	0.109	10.3146	278.7731	12.9593	350.2503889
18.5	0.095	8.989793	242.9674	11.2948	305.2641004
19	0.09	8.516646	230.1796	10.7003	289.1975688
19.5	0.0875	8.280072	223.7857	10.4031	281.164303
20	0.0794	7.513574	203.0696	9.44005	255.1365218

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